MICE HYDROGEN SYSTEM

Overall DSEAR Risk Assessment

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Contents

1 Scope

This risk assessment considers and quantifies the risks associated with explosive atmospheres in the MICE Hydrogen Delivery System. Other types of risks are considered elsewhere.

The risks associated with explosive atmospheres in the ventilation system are considered in a dedicated report produced by Halliday Stack and Dewhirst Loss Prevention Consultants[1] and so are not part of this assessment.

2 Approach and Methodology

The following assessment follows the approach taken by Burgoyne Consultants Ltd (BCL) on a similar installation on the ISIS facility at RAL. The assessment addresses the following questions:

i. Can a flammable (explosible) atmosphere arise in normal or reasonably foreseeable abnormal operation and, if so, how extensive is it likely to be and how likely is it to occur?
ii. Can ignition sources arise within the possible flammable atmosphere? How likely are they to arise in normal and reasonably foreseeable abnormal circumstances and are they likely to be sufficiently energetic to ignite the flammable atmosphere?
iii. What are the consequences in the event of ignition of the flammable atmosphere? In relation to DSEAR the concern is for the safety of people so we must consider the nature and extent of the hazard, how many people may be in the affected area and how likely they are to be present.
iv. What is the most appropriate Basis of Safety and are the existing control measures sufficient to reduce the risks to tolerable levels?
v. If existing control measures are not considered sufficient then what additional controls are required to further reduce the residual risk?

A semi-quantitative risk ranking system is employed, with the scoring system as defined below. This is intended to give an approximate indication of the tolerability of the risks in relation to broad risk category bands and is also of assistance when determining overall priorities for implementing additional control measures.

Flammable Atmosphere

Always/ nearly always present (Zone 0 or 20)	4
Routinely present throughout item volume in normal operation (Zone 1 or 21)	3
Likely in abnormal operation (Zone 2 or 22) or routinely present but very localised	2
May arise in highly abnormal operation	1

[1] 111004-2 Letter Report Rev0_01.pdf

Ignition Source

Effective ignition source likely to arise in normal operation	4
Effective ignition source likely in case of single fault or expected malfunction	3
Effective source possible but unlikely for single fault, likely for multiple faults or rare malfunction	2
Effective ignition source unlikely even for multiple faults or highly abnormal situation	1

Hazard – nature and extent

Flame / pressure effects throughout entire workplace and affecting wider site area outside	4
Flame / pressure effects within workplace beyond immediate vicinity of item	3
Flame / pressure effects within workplace local to item or from relief into occupied area	2
No significant effects within workplace and flame / pressure vented to safe unoccupied area	1

Occupancy

Many employees always present or potential impact on member of the public	4
Several employees routinely present or 1-2 individuals always present	3
Occasional routine presence of few individuals	2
No routine occupancy of area	1

The individual ratings are multiplied together to give an overall risk rating which can fall within 3 broad categories:

0-15: Broadly Acceptable – risks sufficiently low that no further controls need to be pursued.

16-45: Tolerable if shown to be as low as reasonably practicable (TIFALARP) – further controls to reduce risk should be implemented unless they are shown to be grossly disproportionate (in terms of practicability and/or cost) to the resulting risk reduction.

>45: Intolerable – risks are unacceptable and cannot be justified. Additional control measure must be implemented to bring the risks down into the broadly acceptable region or, as a minimum, into the TIFALARP region.

3 Risk Assessment

See following pages.

Note that all areas considered below are designated as ATEX Zone 2.

3.1 Cryostat & Transfer Line Explosion Risk Assessment

Site: RAL **Area:** MICE Hall, R5.2 (inside)	**Equipment Items:** Hydrogen Absorber/Turret and Transfer Line. **Duty:** Liquefy hydrogen delivered from the Gas Panel Enclosure.	
RISK ELEMENT	**CONTROL MEASURES**	**RATING**
Flammable Atmosphere: Creation of a flammable atmosphere is unlikely in normal operation as the cryostat creates a vacuum jacket around the hydrogen vessels and the transfer line jacket is nitrogen purged. A conceivable, but unlikely, scenario is that air may leak into the vacuum space and mix with any hydrogen that has leaked from the inner vessels. Note that mixing can only occur above the freezing temperature of oxygen (90K), so this is only a risk during warm operations.	High integrity stainless steel pipework with metal-to-metal seals throughout. Pipework and internal vessels leak checked and pressure tested to 1.5x maximum expected operating pressure (MEOP) during commissioning. Transfer line is nitrogen jacketed.	2

Ignition Sources: All electrical components inside the cryostat are intrinsically safe with the exception of the heaters.	The heaters are interlocked to be disabled if the pressure in the cryostat vacuum space is ≥10^{-3}mbar.	1
Hazard – nature and extent: Explosion in the cryostat or transfer line. Although these are contained spaces, they would be unlikely to completely confine the explosion and there would be localised effects.		2
Occupancy of affected area: Low occupancy. However, MICE/ISIS personnel may be present in the surrounding area under controlled access to perform filling operations. Personnel are continuously present in control rooms adjacent to the MICE Hall, but the iron magnetic shield wall and concrete outer wall would considerably attenuate a blast for personnel in these areas.	Prevent controlled access during the initial stages of a hydrogen fill and during a hydrogen empty sequence.	2
OVERALL RISK RATING		8

BASIS OF SAFETY:	**ELIMINATE IGNITION SOURCES** Avoidance of flammable atmospheres with control of ignitions sources through intrinsically safe components and interlocked heaters.	
Additional controls required:	None	
ESTIMATED RISK RATING AFTER ADDITIONAL ACTIONS:	2 x 1 x 2 x 2	8
EXPLOSION PROPOGATION RISK: N/A		

3.2 Gas Panel Enclosure Explosion Risk Assessment

Site: RAL **Area:** MICE Hall, R5.2 (inside)	**Equipment Items:** Gas Panel Enclosure including the buffer tank **Duty:** Deliver hydrogen to the Hydrogen Absorber/Turret	
RISK ELEMENT	**CONTROL MEASURES**	**RATING**
Flammable Atmosphere: Although the enclosure is ventilated, oxygen is assumed to be present is sufficient quantities to form an explosive atmosphere. Hydrogen may be released under the following failures: i. Leak from the Gas Panel connections ii. Catastrophic pipework rupture iii. Buffer tank failure	High integrity stainless steel pipework with metal-to-metal seals throughout. Buffer tank is designed to appropriate pressure vessel regulations Pipework leak checked and pressure tested to 1.5x maximum expected operating pressure (MEOP) during commissioning. Gas Panel Enclosure fitted with two hydrogen detectors operating at <25% LEL (Lower Explosive Limit). Enclosure ventilated at 100 air changes/hour under normal operation and 450 air changes/hour if hydrogen is detected.[2]	2

[2] See Zoning report 09(LR)0886.pdf

Ignition Sources: There are various valves, pressure transmitters, temperature sensors and flow meters inside the Gas Panel Enclosure. Electrostatic ignition sources.	All electrical components inside the enclosure are intrinsically safe. Valves are ATEX approved. All equipment adequately grounded.	1
Hazard – nature and extent: Explosion in the Gas Panel Enclosure. This would be likely to affect the south mezzanine area of the MICE Hall.		3
Occupancy of affected area: Low occupancy. However, MICE/ISIS personnel may be present in the surrounding area under controlled access to perform filling operations. Personnel are continuously present in control rooms adjacent to the MICE Hall, but the iron magnetic shield wall and concrete outer wall would considerably attenuate a blast for personnel in these areas.	Personnel would only be allowed in R5.2 during running under controlled access. Beacons and alarms connected to the H2 detectors would alert them of the presence of hydrogen in the Gas Panel Enclosure.	2
OVERALL RISK RATING		12

BASIS OF SAFETY:	**ELIMINATE IGNITION SOURCES** Avoidance of flammable atmospheres through ventilation and good engineering practice.	
Additional controls required:	None	
ESTIMATED RISK RATING AFTER ADDITIONAL ACTIONS:	2 x 1 x 3 x 2	12
EXPLOSION PROPOGATION RISK: N/A		

3.3 Vacuum Pump Enclosure Explosion Risk Assessment

Site: RAL **Area:** Vacuum Pump Enclosure on MICE Hall roof.	**Equipment Items:** Vacuum pumps and pipework **Duty:** Evacuate the Hydrogen Absorber/Turret vacuum space and purge the system pipework and vessels.	
RISK ELEMENT	**CONTROL MEASURES**	**RATING**
<u>Flammable Atmosphere:</u> The purge pump may pass small quantities of hydrogen during purging, although this will not mix with air until the outlet side of the pump. The pumping line is also used as a relief route in the event of an absorber window failure. This would cause rapid boiling of hydrogen in the insulating vacuum. The pressure wave would bypass the two pumps via relief components and the hydrogen would vent into the ventilated pump enclosure.	The Vacuum Pump Enclosure is continuously ventilated at 75 air changes/hour.[3] Hydrogen detectors are fitted to the exhaust of the cryostat backing pump (VP2b) operating at <25% LEL.	2

[3] See MICEH2-RQ-101101

Ignition Sources: Electrical equipment (lighting, heaters) inside Vacuum Pump Enclosure.	All electrical items inside the Vacuum Pump Enclosure are ATEX rated. Heaters are spark proof.	3
Hazard – nature and extent: An explosion in the Vacuum Pump Enclosure would also have localised effects around the enclosure.		2
Occupancy of affected area: Access to the Hall roof is prevented signed barriers during operation.		2
OVERALL RISK RATING		24
BASIS OF SAFETY:	**ELIMINATE IGNITION SOURCES** Ignitions sources are eliminated through ATEX rated components (suitable for Zone 2).	

Additional controls required:	Access to the enclosure will be strictly controlled, with the single key being incorporated into the control system panel such that a warning is sounded if it is removed during hydrogen operations.	
ESTIMATED RISK RATING AFTER ADDITIONAL ACTIONS:	2 x 3 x 2 x 1	12
EXPLOSION PROPOGATION RISK: N/A		

3.4 Vacuum Pipework Explosion Risk Assessment

Site: RAL **Area:** MICE Hall R5.2 (inside) and external pipework outside the south wall of R5.2	**Equipment Items:** Vacuum pipework **Duty:** Evacuate the Hydrogen Absorber/Turret vacuum space and purge the system pipework and vessels.	
RISK ELEMENT	**CONTROL MEASURES**	**RATING**
<u>Flammable Atmosphere:</u> The purge pump may pass small quantities of hydrogen during purging, although this will not mix with air until the outlet side of the pump. The pumping line is also used as a relief route in the event of an absorber window failure. This would cause rapid boiling of hydrogen in the insulating vacuum. The pressure wave would bypass the two pumps via relief components and the hydrogen would vent into the ventilated pump enclosure.		2

Ignition Sources: None inside the pipework Area outside is well ventilated.		1
Hazard – nature and extent: An explosion in the vacuum pipework may rupture the joints and cause localised effects.		2
Occupancy of affected area: Low occupancy. However, MICE/ISIS personnel may be present in the surrounding area under controlled access.		2
OVERALL RISK RATING		8
BASIS OF SAFETY:	**ELIMINATE IGNITION SOURCES** Ignitions sources are eliminated.	

Additional controls required:	None	
ESTIMATED RISK RATING AFTER ADDITIONAL ACTIONS:	2 x 1 x 2 x 2	8
EXPLOSION PROPOGATION RISK: N/A		

3.5 Hydrogen Bottle Stand Explosion Risk Assessment

Site: RAL **Area:** MICE Hall R5.2 (outside)	**Equipment Items:** Caged enclosure, regulator, hydrogen bottles and pipework **Duty:** Supply hydrogen for liquefaction in the Hydrogen Absorber.	
RISK ELEMENT	**CONTROL MEASURES**	**RATING**
<u>Flammable Atmosphere:</u> Hydrogen may be released during bottle connections. There may be small leaks from pipework fittings. Vehicular collision could cause release of hydrogen from damaged pipework or fittings.	The enclosure is situated outside with free space directly above and all around, creating a significant dilution effect. Bollards and barriers are positioned to protect the enclosure from collisions with cars and forklift trucks.	2

Ignition Sources: Sparking of hand tools on the bottle/regulator/pipework. Electrostatic spark	Non-sparking tools will be used when making bottle connections.	2
Hazard – nature and extent: Any ignited mixture would release upwards into free space.		3
Occupancy of affected area: Public thoroughfare.		4
OVERALL RISK RATING		48
BASIS OF SAFETY:	**ELIMINATE IGNITION SOURCES** Elimination of flammable atmospheres through ventilation and control of access.	

Additional controls required:	Ensure antistatic clothing is worn during operations. Enclosure and bottle to be appropriately grounded. Warning signs and temporary barriers to be erected during bottle connection to exclude members of the public and limit exposure to hydrogen operators only. Bottle connection to be carried out during non-working hours (after 6pm) to further limit exposure. Warning signs and a general exclusion zone to be created for vehicle drivers.	
ESTIMATED RISK RATING AFTER ADDITIONAL ACTIONS:	2 x 2 x 3 x 3	36
EXPLOSION PROPOGATION RISK: N/A		

4 Conclusions and Recommendations

The general basis of safety for the system is to avoid the formation of flammable atmospheres through the separation of hydrogen and oxygen, or appropriate levels of ventilation. Where it may not be possible to entirely guarantee this, reduced occupancy is used for additional protection.

Wherever practicable, ignition sources are eliminated through interlocks or intrinsically safe components.

The quantitative risk assessment tables highlight that the Hydrogen Bottle Stand during bottle connection is a higher risk area. Although hydrogen filling is expected to be a rare operation (< 3 times in total), special consideration should be given to the procedures for this operation. It is noted that there is precedent for this kind of installation elsewhere on site.